

# A 100 GHz Coplanar Strip Circuit Tuned with a Sliding Planar Backshort

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**Abstract**—A means of mechanically altering the electrical length of a planar transmission line would greatly enhance the use of integrated circuit technology at millimeter and submillimeter wavelengths. Such a mechanically adjustable planar RF tuning element, successfully demonstrated at 100 GHz, is described here. It consists of a thin metallic sheet, with appropriately sized and spaced holes, which slides along on top of a dielectric-coated coplanar-strip transmission line. Multiple RF reflections caused by this structure add constructively, resulting in a movable RF short circuit, with  $|s_{11}| \simeq -0.3$  dB, which can be used to vary the electrical length of a planar tuning stub. The sliding short is used here to produce a 2-dB improvement in the response of a diode detector. This tuning element can be integrated with planar circuits to compensate for the effect of parasitic reactance inherent in various devices including semiconductor diodes and superconductor-insulator-superconductor (SIS) junctions.

## I. INTRODUCTION

THE allure of highly integrated components and systems makes planar transmission line circuits attractive for use at frequencies in the millimeter wave spectrum and beyond. At these frequencies, planar transmission line circuits are straightforward to fabricate and can provide seamless integration with various planar devices. However, the devices used in these circuits often have large parasitic reactances which require compensation to be included in the circuit. Consequently, at the highest frequencies in state-of-the-art systems, planar devices must often be implemented in tunable waveguide embedding circuits in order to extract optimum performance [1], [2]. The objective of this work is to demonstrate a mechanical means of tuning planar circuits, analogous to non-contacting waveguide backshorts. A sliding metal pattern, used to form a movable RF short circuit on a planar transmission line by spatially modulating the impedance, is introduced. This sliding, planar backshort can be readily fabricated by a variety of techniques, including micromachining techniques [3], which are particularly useful for short millimeter wavelength and submillimeter wavelength applications where characteristic dimensions are very small.

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## II. DESIGN AND FABRICATION

The sliding short used in this experiment is based on a recently patented design [4] and consists of a movable metal sheet, with appropriately sized and spaced holes, placed on top of a dielectric-coated coplanar-strip transmission line, as shown in Fig. 1. In this position, the metal pattern is designed to create a sequence of alternating low- and high-impedance quarter-wavelength sections of transmission line, resulting in a broadband RF short circuit. Critical dimensions for the transmission line and sliding short are scaled, by frequency, from an empirically designed 2-GHz model [5].

The performance of the sliding short was tested in a 100-GHz detector circuit based on an existing 230-GHz planar heterodyne receiver [6]. This quasi-optical design utilizes a dielectric-filled parabola to focus an incident RF signal onto a planar dipole antenna. A GaAs Schottky beam-lead diode mounted across the antenna is used as the detector. DC bias and detector output are carried by the coplanar strips.

The antenna circuit and the sliding short were fabricated by thermal evaporation of thin conducting films onto separate quartz wafers, each 250  $\mu\text{m}$  thick. A 0.28  $\mu\text{m}$  Cr/Au film was used for the antenna circuit and a 0.27  $\mu\text{m}$  Cr/Ag/Cr film was used for the sliding short. A photoresist liftoff stencil was used to define the geometry for each of these circuits. The quartz wafer served as a dielectric substrate for the antenna circuit. For the sliding short, however, the quartz wafer merely served as a support structure, providing a convenient means for achieving the high degree of flatness required at this frequency.

The antenna circuit consisted of a 936  $\mu\text{m}$ -long, 87  $\mu\text{m}$ -wide metal-film dipole, center fed by two 50  $\mu\text{m}$ -wide metal-film strips as shown in Fig. 1(a). A 100  $\mu\text{m}$  gap separated the two strips and split the dipole. A thin layer of polyimide was spun onto the circuit and cured to a final thickness of 0.5  $\mu\text{m}$ . Small windows were reactive ion etched from the polyimide, in an oxygen plasma, to allow for attachment of the diode to the antenna and dc wires to the other end of the transmission line. The sliding short consisted of a rectangular metal-film pattern with two centered rectangular holes along its length. When positioned as shown in Fig. 1, three 486  $\mu\text{m}$  sections of transmission line are covered by the metal film, forming the lower impedance sections, with two sections, 388  $\mu\text{m}$  and 460  $\mu\text{m}$  long, left uncovered by the holes. A dicing saw was used to cut the quartz-backed sliding shorts to an appropriate size.

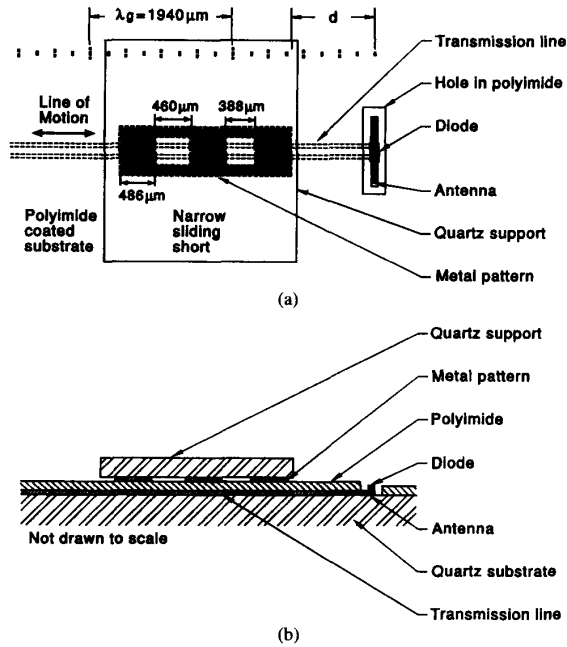


Fig. 1. Top view (a) and cross section (b) of the mechanically tunable planar detector circuit. The metal pattern is moved along the transmission line to provide an adjustable impedance in parallel with the diode.

### III. EXPERIMENTAL RESULTS

Measurements were made with the detector circuit mounted on the dielectric-filled parabola with the sliding short, positioned metallization side down, resting freely on top of the polyimide-coated transmission line. The circuit was positioned horizontally beneath a flat copper reflector aligned to direct a 100-GHz signal onto the circuit. An HP 83620A synthesized oscillator with an HP 8355A millimeter wave source module was used as the signal source. The source power was set to 0 dBm with an internal 1-KHz square wave modulation, and an EG&G 5210 lock-in amplifier was used to monitor the detected power. Positioning marks were included in the antenna circuit pattern so that the sliding short could be manually aligned at various distances, dimension  $d$  in Fig. 1(a), from the antenna and diode with the aid of a microscope.

The circuit was tested by manually aligning the sliding short, with the aid of a sharp wooden probe, at increments of  $\lambda_g/16$  along the transmission line and measuring the detector response at each position. The wavelength ( $\lambda_g$ ) used here was that for the coplanar strip transmission line, and the sliding short was positioned up to three wavelengths away from the antenna and diode. This procedure was repeated using two sliding short designs, both having identical dimensions along the transmission line, but one with a wider metallization pattern across the line. The diode was dc-biased at  $200\mu\text{A}$ , and results for both the narrow ( $0.34\lambda_g$ ) and wide ( $0.77\lambda_g$ ) sliding shorts are shown in Fig. 2, normalized to the response measured with no sliding short present (typically  $160\mu\text{V}$ ).

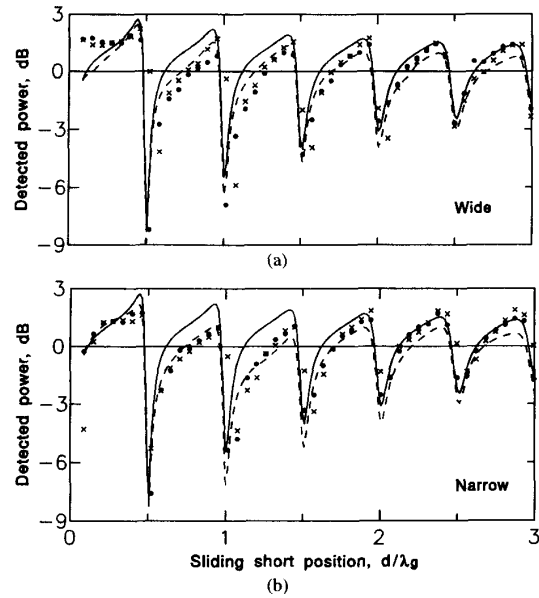


Fig. 2. Data for two typical trials (●)(×) is shown for both the wide (a) and narrow (b) sliding shorts. Theory is shown both without (—), and with (---) the coupling effect included.

A theoretical model for the circuit was developed. Circuit parameters for the beam-lead diode (M/A-COM MA40417) were taken from the manufacturer's specifications. A resistance of  $50\Omega$  was used for the antenna impedance [6]. The transmission line impedance ( $190\Omega$ ) and effective dielectric constant (2.4) were calculated using quasi-static closed-form expressions [7]. Loss for the line ( $0.83\text{ dB}/\lambda_g$ ) was calculated as a sum of radiation loss into the substrate ( $0.15\text{ dB}/\lambda_g$ ) [8], and conductor loss ( $0.68\text{ dB}/\lambda_g$ ) [7] calculated using the measured dc conductivity ( $1.5 \times 10^7\text{ S/m}$ ). The sliding short was modeled with  $|s_{11}| = -0.3\text{ dB}$ , as measured in the 2-GHz experiment [5]; changes due to material variations and increased skin effect at this frequency were not included because the experiment was not expected to be accurate enough to show these effects. The calculated circuit response is included in Fig. 2.

A parasitic coupling effect between the sliding short and the antenna was also observed. This was characterized by repeating the measurements with the sliding short moved incrementally away from the antenna as before, but now positioned on the side of the antenna exactly opposite to the transmission line. In this way the parasitic coupling between the antenna and sliding short could be recreated, isolated from the transmission line effect. The measured coupling effect, a perturbation of as much as  $-2\text{ dB}$ , was then added to the theoretical response, and is also shown in Fig. 2. This compensation improves agreement between theory and measurement for positions less than  $2\lambda_g$ .

### IV. DISCUSSION

In this experiment, a new approach for tuning planar circuits was successfully demonstrated at millimeter wavelengths. The

detector response was increased by more than 2 dB over the untuned response at the peak position and nulled by nearly 11 dB at the  $\lambda_g/2$  position. Also, the theory was shown to adequately predict the circuit performance.

The circuit used here demonstrates the concept and other circuits could be designed to take even better advantage of the sliding short. A different device, such as a monolithically fabricated diode or SIS tunnel junction, could be used as the detector and a second tuning stub could be incorporated to provide further improvement in the response. Future versions of the sliding short could be fabricated on the transmission line itself, captivated by a micromechanical guiding structure with an integral means of electromechanical drive[3].

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